THE LASER ULTRASONIC INSPECTION SYSTEM (LUIS) AT THE SACRAMENTO AIR LOGISTICS CENTER

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INTRODUCTION

The proportion of composite parts used in new Air Force aircraft is increasing significantly with each airplane that is designed [1]. In addition, composite parts are also being used for critical applications, where the loss of the part could cause the loss of the plane. These parts are susceptible to delaminations, disbonds, and impact damage. As part of its mission to overhaul aircraft, the Sacramento Air Logistics Center needs to be able to efficiently validate the integrity of composite aircraft parts.

Squirter based inspections are the conventional method for inspecting composite parts. The ultrasound is generated and detected using piezoelectric transducers, and is propagated to and from the part through streams of water produced by the squirters. Squirter inspections of flat parts are easy, because the orientation of the squirters can be set once, and they can then be scanned across the surface of the part.

Squirter based inspections of composite parts with complex geometries, on the other hand, are difficult, expensive and time consuming. Because the squirters must be oriented normal to the surface of the part, the precise shape of the part needs to be known before the scan plan can be generated. Then, the process of designing a scan plan, specifying the location and angles of the squirters, and making sure that all points on the part are adequately inspected, can take weeks. Many parts also require new and expensive fixturing, so that the part can be held in a known position and geometry for the scan plan to be valid. Squirter systems also take significantly more time to inspect parts with complex geometries, because it takes time for the squirter systems to move and orient each squirter.

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Laser Based Ultrasonic (LBU) inspections can be much faster than squirter based inspections because there is no requirement for the laser beams to be normal to the surface of the part. LBU systems use a short pulse of laser light to generate a pulse of ultrasound [2]. This ultrasound propagates normal to the surface of the part, and reflects off delaminations and defects within the part. These ultrasonic echoes are detected using an interferometer. Neither the laser beam which generates the ultrasound nor the one which detects the ultrasonic echoes needs to be normal to the surface of the part [3]. Therefore it is not necessary to know the shape of the part in advance to set up a scan plan, and the scan plans typically require less than five minutes to set up. LBU systems can also inspect parts much faster than squirter systems, because the laser beams which generate and detect ultrasound can be rapidly scanned across the surface of the part using a laser scanning mirror.

The Sacramento Air Logistics Center (SM-ALC/TIMSN) has procured a Laser Ultrasonic Inspection System (LUIS) to inspect its workload of composite aircraft parts. This is the first LBU system to be installed in a production environment for inspecting 500 square feet of composite parts per 8 hour shift. Because this system is unique, the system will be described in detail, and results of inspections using the system will be presented.

DESCRIPTION OF THE LUIS SYSTEM

The operating parameters specified for the LUIS system were determined by a study conducted by NRE [1]. The system was built by UltraOptec of Boucherville, Quebec and passed its final acceptance test on February 12, 1996.

The LUIS system, shown in Figure 1, is located in a main inspection bay and attached control room. The LUIS inspection head is mounted on a gantry robot. The inspection head contains the (1) generation laser which produces the pulses of light which are used to generate ultrasound, (2) laser ranging system, (3) focusing system for the generation and detection laser beams, (4) HeNe pointing laser to indicate the path the generation and detection laser beams will take, (5) computers to monitor the lasers, acquire data from the ranging system and control the focussing system, and control and monitor the laser scanning mirror, and (6) a Cassegrain light collection system for the interferometer.
The control room contains the (1) detection laser which generates the light used to detect ultrasonic echoes, (2) Fabry-Perot interferometer which is used to detect ultrasonic echoes, (3) computer to digitize the waveforms from the interferometer, (4) main workstation to control the LUIS system and to display the progress of the inspection, (5) secondary workstation which allows previously collected scans to be analyzed while the primary workstation is acquiring new data, and (6) uninterruptable power supply for the LUIS system. The generation and detection lasers, scanning mirror, operation of the system, and data presentation software will be described in more detail.

The generation laser is a CO_2 laser which produces 130 ns long pulses of light at a wavelength of 10.6 μm. The laser is capable of producing pulses with an energy of 200 mJ, but 100 mJ is sufficient for inspecting most composites.

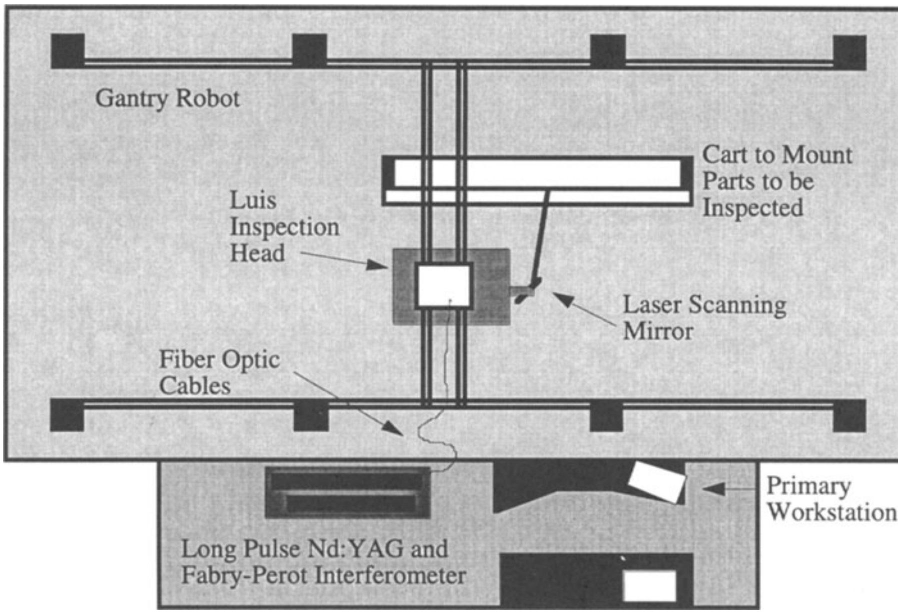

Figure 1. Schematic drawing of the LUIS inspection system.

The detection laser is a specially designed long pulse Nd:YAG laser. The sensitivity of the interferometer is dependent on the amount of light collected and passed through the interferometer. To maximize this amount of light, the detection laser is designed to produce 500W of power during the 50ms the system is detecting ultrasonic echoes. This laser uses a very stable diode pumped mini-YAG oscillator as a seed source, and is amplified with flashlamp pumped Nd-YAG amplifiers. The 1.64 μm wavelength light which is generated by this laser can be efficiently transmitted to and from the part using conventional fiber optics. The interferometer is a 1.0 m Fabry-Perot interferometer with an etendue of 0.33 mm^2, and is shot noise limited.

The generation and detection laser beams are scanned across the surface of the specimen using a laser scanning mirror which can rotate in two directions. To maximize the light collected from the specimen for the interferometer, this scanning mirror and the Cassegrain collection system have an effective aperture of 6.0 in. in diameter. The gantry robot is used to position the LUIS inspection head such that this mirror is 5.0 feet from the specimen, and the mirror scans the laser beams in 0.2, 0.1 or 0.05 inch increments. This mirror and the parts mounted for inspection are shown in Figure 2.

Both lasers, the scanning mirror and data acquisition system can inspect 100 points per second. This allows the LUIS system to inspect 500 square feet of complex composite parts in an 8 hour shift.

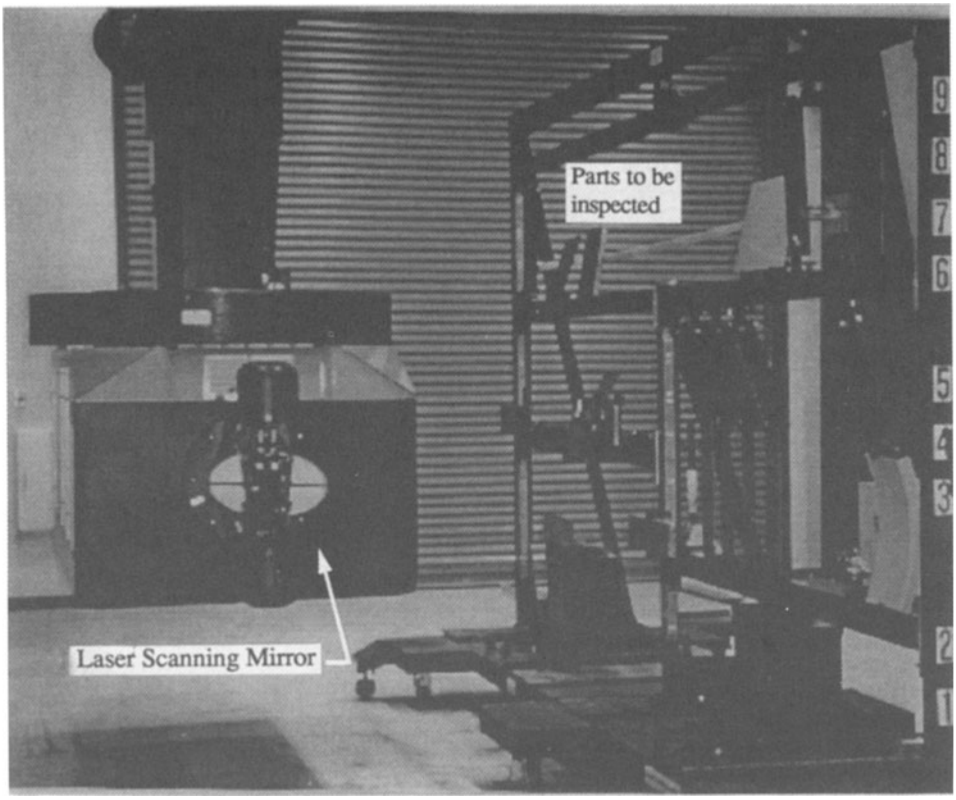

Figure 2. LUIS inspection head showing the laser scanning mirror.

The LUIS system also has a laser ranging system which enables it to measure the geometry of the part being inspected. This ranging system uses laser triangulation and can measure distances to within 0.2 inches. This system is also used to control the lenses which focus the laser beams to a 0.1 inch diameter spot on the surface of the part.

The LUIS inspection head is mounted on a gantry robot which allows it to inspect parts as large as a Harrier wing, 42 feet long by 11 feet high, in a series of scans. Each scan can cover a region as large as 6 feet by 6 feet, and all of the scans can be displayed as a single image using the workstation software.

The primary workstation for the LUIS system is a Silicon Graphics Indigo Extreme, and is used to set up the LUIS scans, to display the A,B, and C-scans while the inspection is occurring, to process the data after the scan is complete, and to archive the data. The routine running of the lasers, controlling the scanning mirror, digitizing signals from the interferometer, logging data from the ranging system, and controlling the gantry robot are handled with five IBM PC's which are built into the system. This modular design allows the different software modules to be developed, debugged and upgraded indepedently, which reduced the software development time and improved reliability.

LUIS INSPECTION RESULTS

The signal to noise ratio and fidelity of LUIS A,B, and C-scans are as good or better than the inspection results from the SM-ALC squirter system for flat graphite epoxy parts. A typical LUIS A-scan from a 0.25 inch thick graphite-epoxy part is shown in Figure 3. The ultrasonic echoes are clearly resolvable.

The LUIS data from a graphite-epoxy step wedge with 0.5 inch diameter flat bottomed holes was compared to the actual depth and diameters of the holes. The LUIS system very accurately measured the depth of these holes, as shown in Figure 4. The diameters of the holes were measured by determining the maximum extent of the defect indication on the C-scan display. This method did not account for the finite size of the laser beams and as a result tended to overestimate the sizes of the flat bottomed holes. The data in Figure 4 also shows the that LUIS system detected defects which were only 0.082 inches from the surface. The locations of the flat bottom holes were also measured, and Figure 5 shows that the LUIS system accurately located both the x and y locations of the holes.

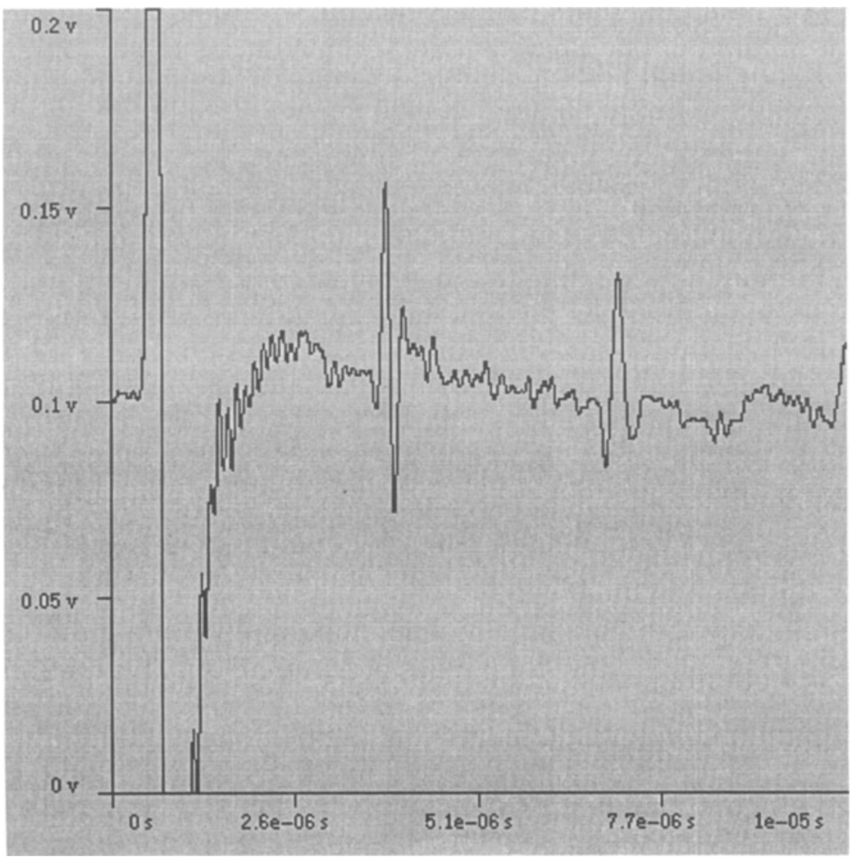

Figure 3. Typical LUIS A-Scan. This A-scan is from a 0.25 inch thick piece of graphite epoxy.

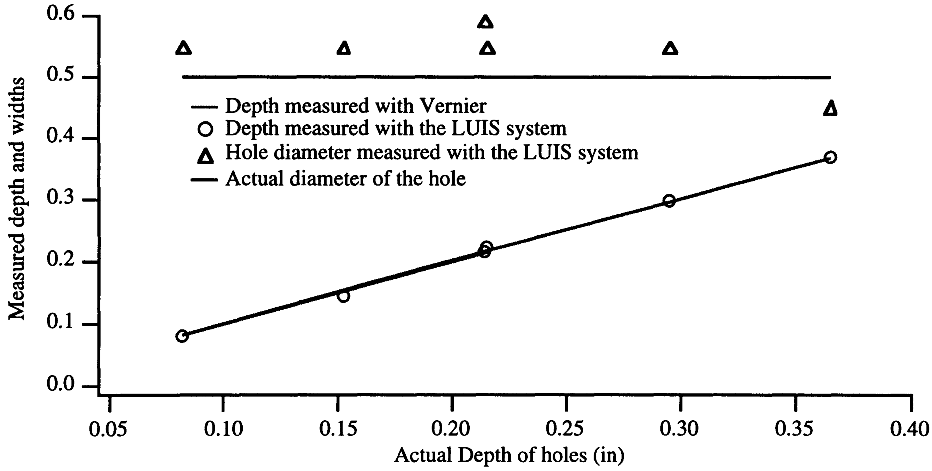

Figure 4. The depth and size of flat bottomed holes in graphite-epoxy as measured with the LUIS system.

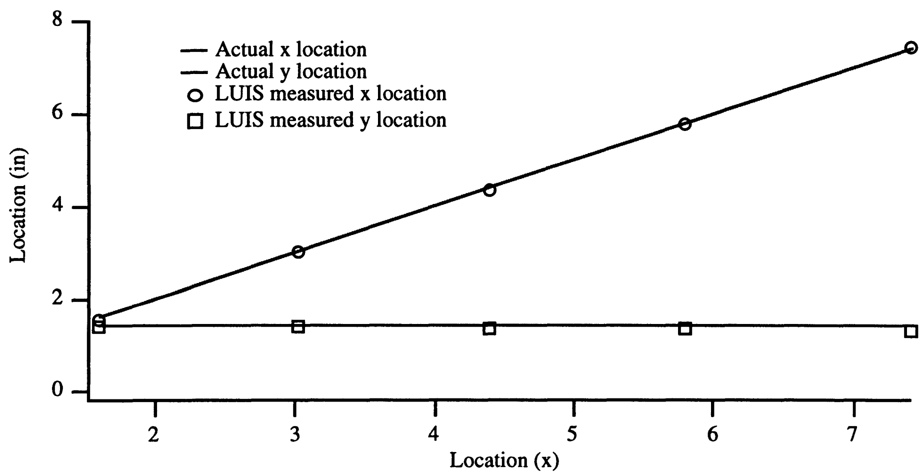

Figure 5. X and Y location of holes as measured with the LUIS system.

The LUIS amplitude C-scan data was compared to the results from the SM-ALC squirter system on composite specimens which had impact damage. The specimen, a 24 ply thick, 0,90 stacking sequence graphite epoxy specimen 0.126 inches thick is shown in Figures 6 and 7. This specimen was impacted with 12.5 in-lbs of energy. The impact damaged region is clearly visible in both the LUIS and squirter data. Moreover, the shape of the impact damage is clearly resolvable in both images. These results demonstrate that the LUIS results are equivalent to the conventional squirter inspection results, at least for specimens which are flat.

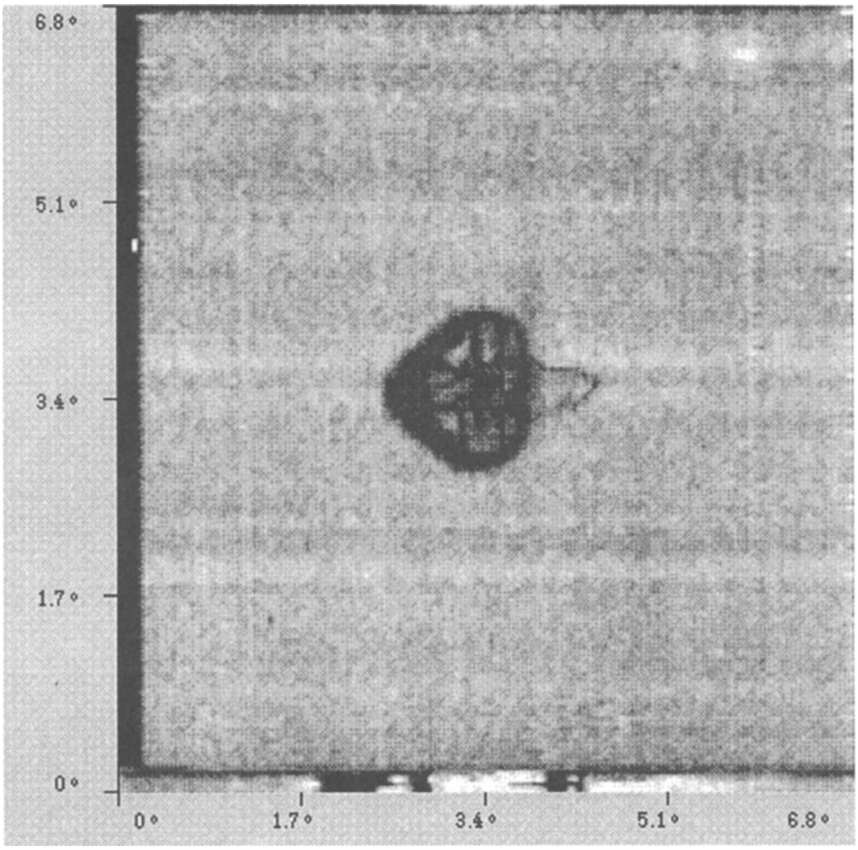

Figure 6. LUIS C-scan of impact damage.

CONCLUSIONS

The LUIS system is a production inspection system. It is installed in a production ALC environment, and it has sufficient speed and reliability to inspect a production workload of parts from Air Force Aircraft.

The LUIS system can reproduce the results of squirter inspections on flat parts. A side by side comparison of squirter and LUIS results on a specimen with impact damage demonstrates that both systems detected and imaged the defect in the specimen. Data from the flat bottomed hole specimen demonstrates that the LUIS system can detect, size and locate flat bottom holes, and can very accurately measure the depth of these defects.

The other advantages of the LUIS system, its ability to inspect 500 square feet of complex composite parts per 8 hour shift with little or no setup time and its ability to display the defect locations on the three dimensional image of the part has already been demonstrated, and the results will be presented in the upcoming months. Because of these advantages, the authors highly recommend that LUIS scans be considered for inspecting production workloads of composite parts, with or without complex geometries [4].

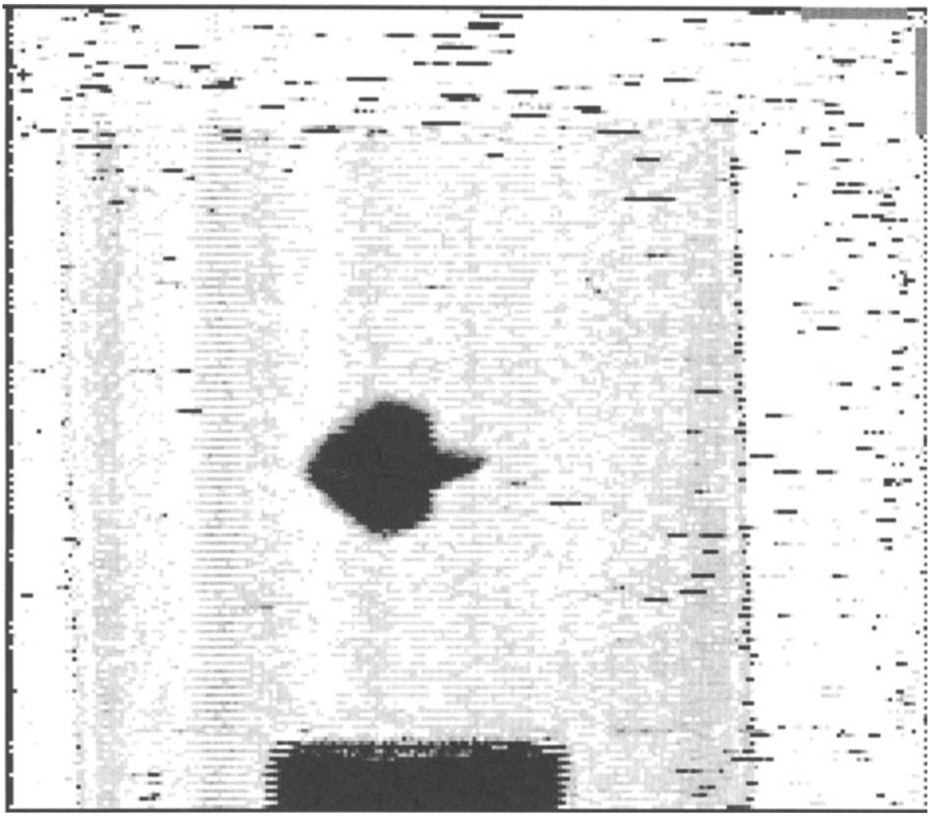

Figure 7. Squirter C-scan of impact damage.

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2. Scruby, C.B. and Drain L.E. Laser Ultrasonics: Techniques and Applications. Bristol: Adam Hilger, 1990.
3. McKie, D.W. and Addison, R.C. "A Laser-Based Ultrasound System Incorporating a Long Pulse Probe Laser for Increased Sensitivity." Review of Progress in Quantitative Nondestructive Evaluation. Ed. D.O Chimenti Thomson, D.E. New York: Plenum, 1994. Vol. 13.
4. The LUIS system is available for scanning production workloads for either government or private industry. For information contact Mike Mattos, NDI Section Chief, SM-ALC/TIMSN at (916) 643-4710.